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EXPERIMENTAL INVESTIGATION OF TEMPERATURE PATTERNS IN THE IPR-R1 TRIGA NUCLEAR REACTOR

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ABSTRACT

Experimental and analytical studies have been performed, at Nuclear Technology Development Center - CDTN (Belo Horizonte), to find out the temperature distribution in the IPR-R1 TRIGA Research Nuclear Reactor as a function of power and position in the reactor core. The basic safety limit for the TRIGA reactor system is the fuel temperature, both in steady-state and pulsed mode operation. The time-dependence of temperature will note be considered here, hence only the steady-state temperature profile will be studied. The experimental results for fuel and coolant temperatures in the reactor core, at different reactor power levels, have been compared with theoretical data and some results from others TRIGA reactors.

1. INTRODUCTION

The 250 kW IPR-R1 Reactor of the Nuclear Technology Development Center (CDTN) is cooled by natural circulation, like other TRIGA reactors. The reactor core (Fig. 1) has 59 aluminum-clad fuel elements and 5 stainless steel-clad fuel elements with 20 % enrichment and 8.5 wt % in uranium. One of these steel-clad fuel elements, shown in Fig. 1, is instrumented with three thermocouples positioned along its centerline. Experiments were made in order to evaluate the thermal hydraulic performance of the IPR-R1 reactor. The temperature distribution under steady-state condition was measured as a function of the reactor power and of the position in the reactor [1]. Temperatures were measured in many locations throughout the reactor pool, in the fuel element centerline and in the coolant channels in the core.

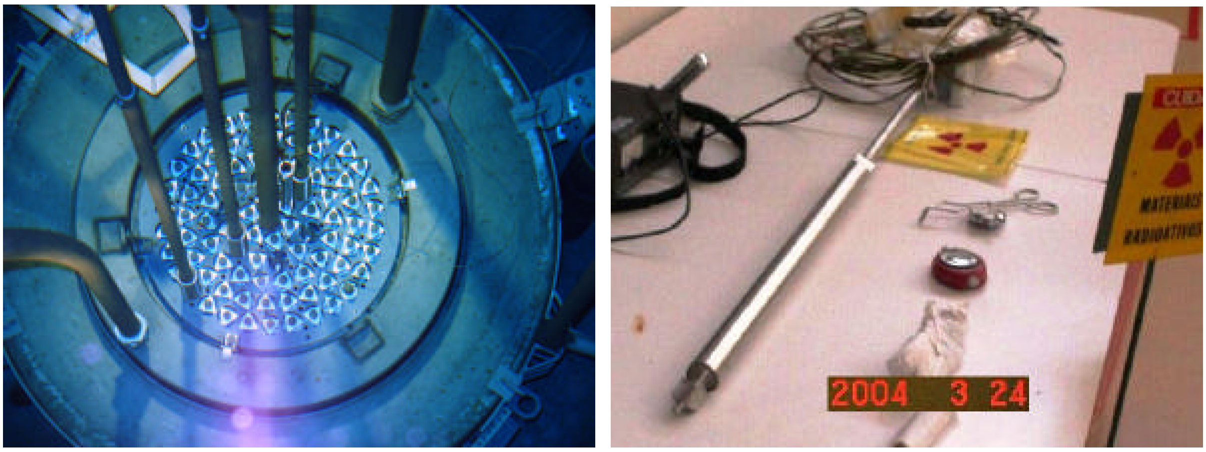

Fig. 1: Top view of the IPR-R1 TRIGA core and the instrumented fuel element

Data are obtained from the console and from a data acquisition system computer that was developed as part of this research project [2]. Some of the parameters collected are power, fuel and channel temperatures, water flow, and control rod insertion position.

2. TEMPERATURE DISTRIBUTION IN THE CORE AND IN THE POOL

The original fuel element at the reactor core position B1 was removed and replaced by an instrumented fuel element with three type K thermocouples positioned along the fuel centerline (Fig. 1 and Fig. 5). Position B1 is the hottest location in the core, according to the neutronic calculation [3]. Two type K thermocouples were inserted into the core in two channels close to position B1 and measured the inlet and outlet temperatures in the hot channel. Nine thermocouples and one platinum resistance thermometer were used to monitoring the reactor pool temperature. The thermocouples were positioned in a vertical aluminum probe and the first thermocouple was 143 mm above the core top grid plate. The reactor thermal power calibration was carried out at 250 kW [4]. After finding the power reference value, the instrumented fuel element was replaced to new positions in each one of the fuel rings from B to F. At the same way, the two coolant channel thermocouples were replaced to channels close to the instrumented fuel element. Experiments were carried out with the power changing from about 50 kW to 250 kW in 50 kW steps for each position of the instrumented fuel element.

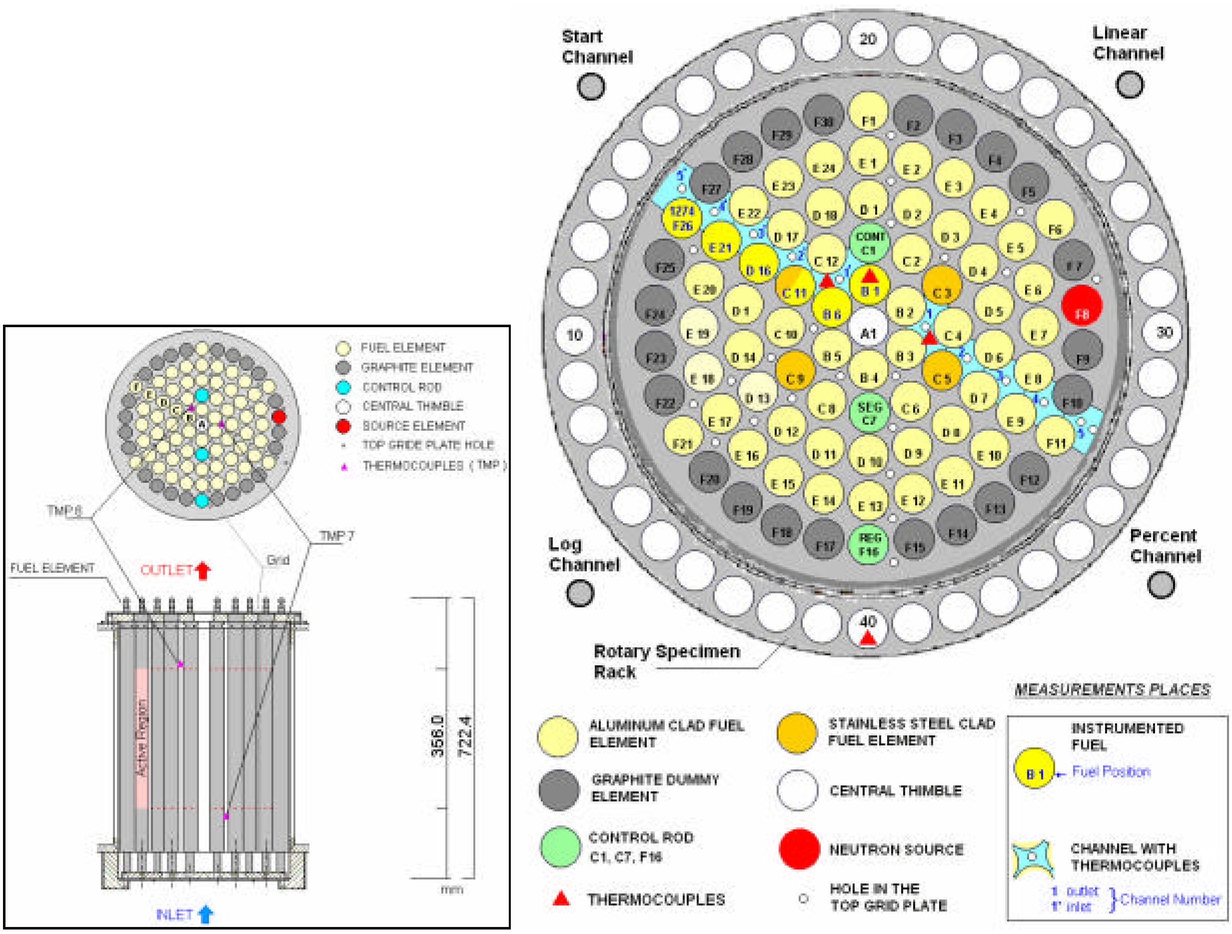

Figure 2. Temperature measures places in the reactor core

Figure 3 shows the theoretical radial power profile [5] and the experimental fuel temperature and the inlet/outlet coolant temperatures in the channel that is the closest to the instrumented element, for the power of 265 kW. The experimental results found in the I.T.U. TRIGA Mark II Reactor at the Istanbul University [6] were also plotted on the same graphic. Figure 4 shows the experimental profiles of inlet and outlet channel coolant temperature together with the same temperature curves calculated using the PANTERA code [7]. Results of fuel temperature versus power experiments are shown in Fig. 5 for each core ring as a function of the reactor thermal power.
The experimental coolant exit temperature for each core ring is shown in Fig 6 as a function of the reactor power. The shape of these curves is similar to that predicted by the theoretical model.

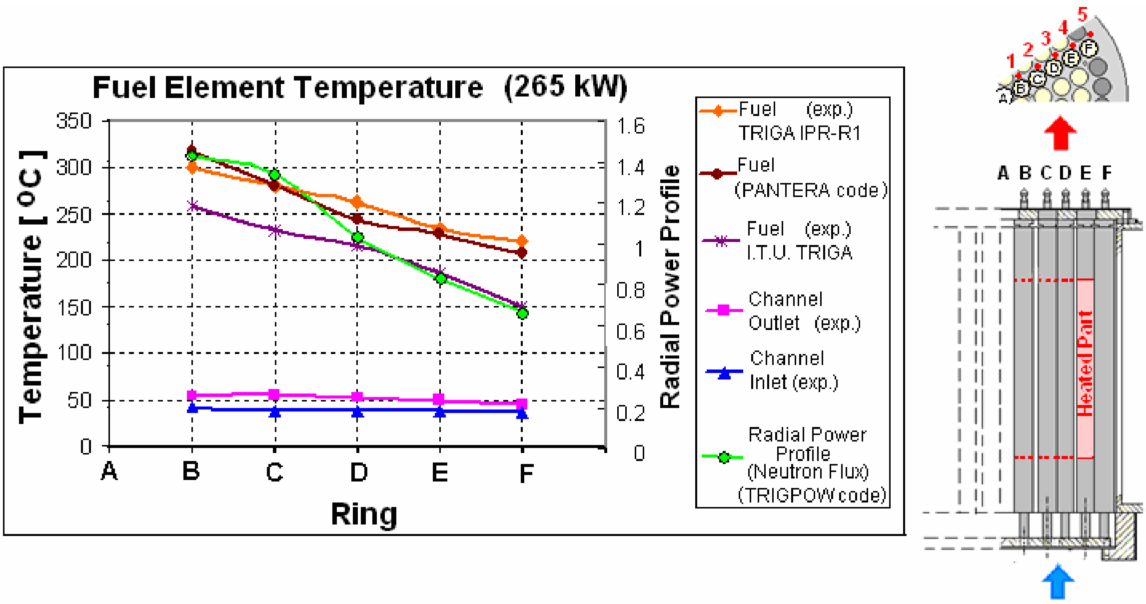

Figure 3. Core temperature radial profile at 265 kW thermal power

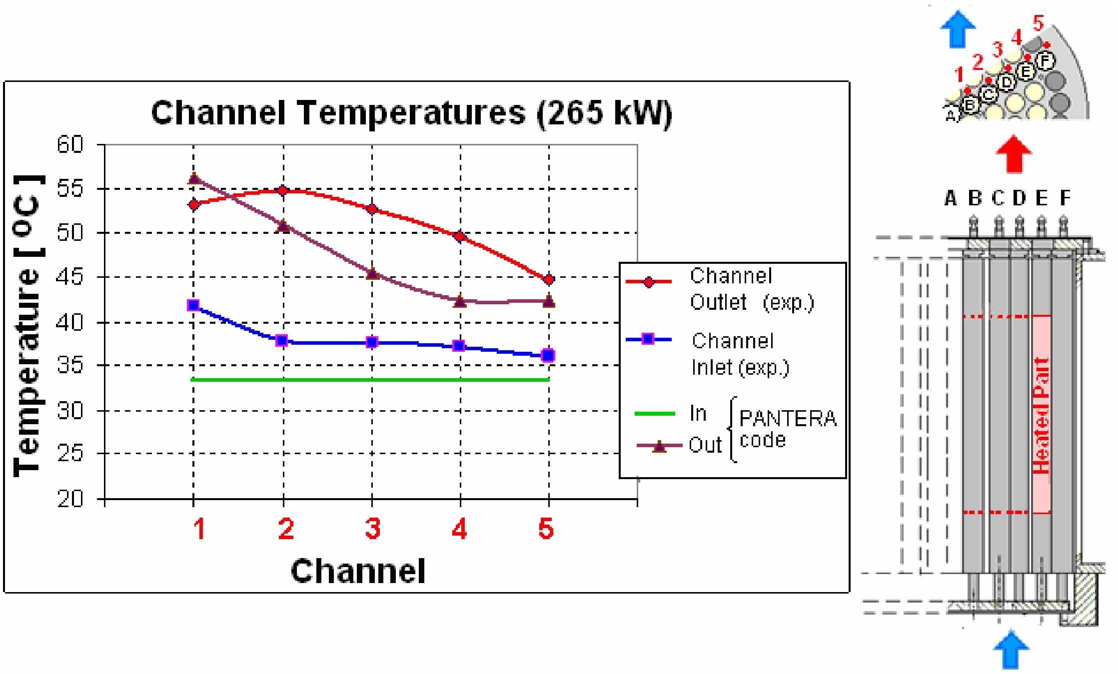

Figure 4. Temperature radial profile in the core channels at 265 kW thermal power

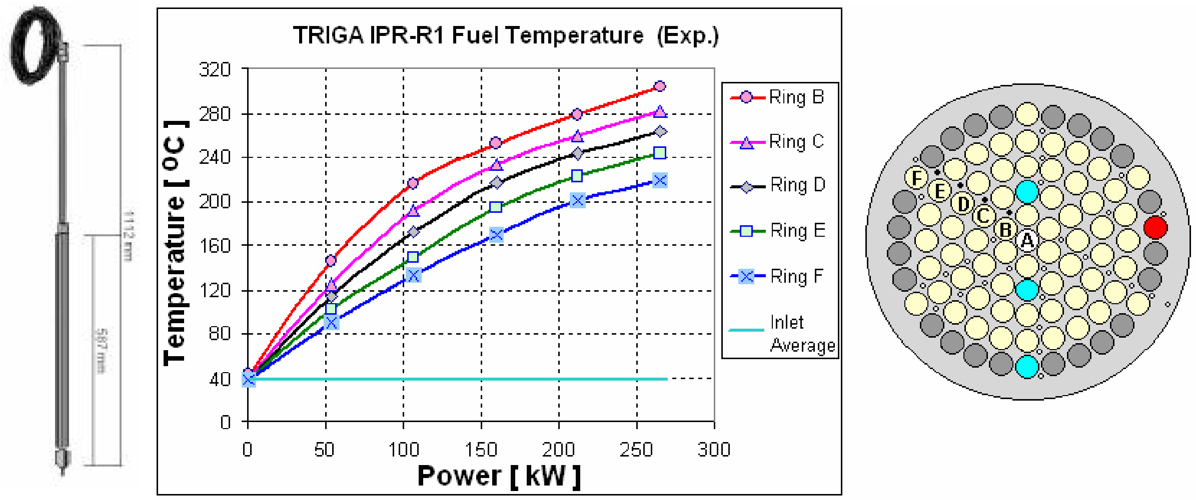

Figure 5. Fuel temperature as function of the reactor power in all core rings

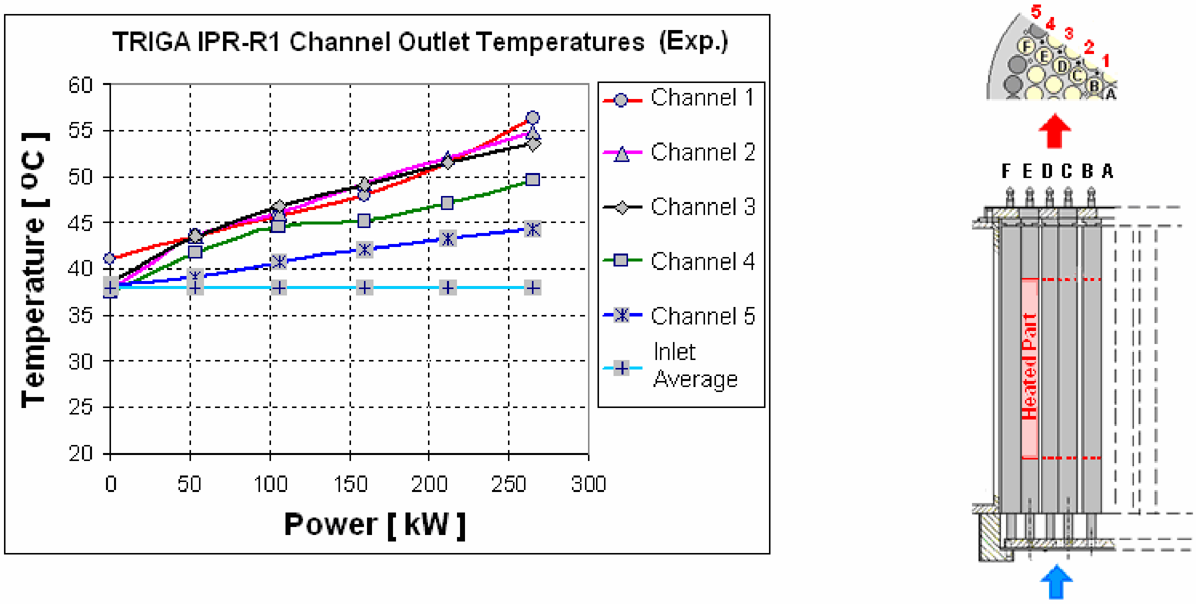

Figure 6. Outlet coolant temperature as function of the thermal power

2.1. Temperature Profile in the Channel

The experimental temperature profile of the coolant water in Channel 1' is shown in Fig. 7 as a function of the axial position, for the powers of 265 kW and 106 kW. The shape of these curves is different from that predicted from the theoretical model (PANTERA Code) [7]. Ideally, the coolant temperature would increase along the entire length of the channel, because heat is being added to the water by all fuel region in the channel. Experimentally, the water temperature reaches a maximum near the middle length and then decreases along the remaining channel. Figure 7 shows also the experimental results for other TRIGA reactors [8], [9] and [10].

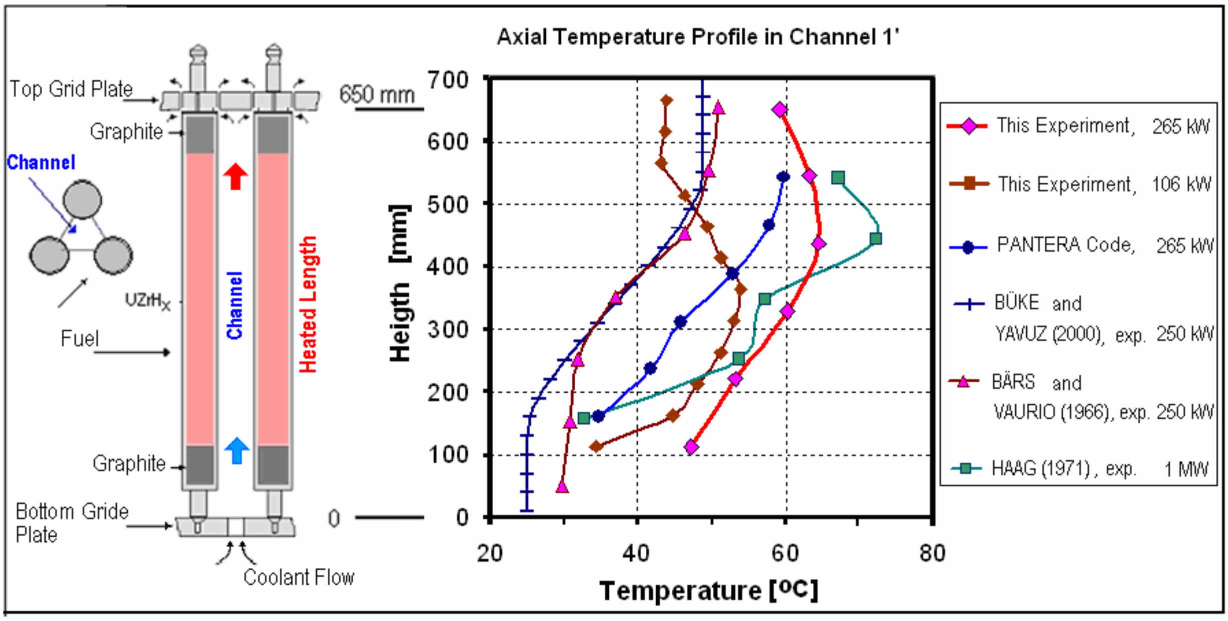

Figure 7. Temperature profile along the Channel 1'

2.2. Pool Temperature

The reactor operated during a period of about eight hours at a thermal power of 265 kW before the steady state was obtained. Figure 8 shows the water temperatures evolution at the reactor pool, and the inlet and outlet coolant temperature in the core's hottest channel, up to the begin of the steady state. The results showed that the thermocouples positioned 143 mm over the top grid plate (Inf 7) measure a temperature level higher than all the other thermocouples positioned over the reactor core. It means that the chimney effect is not much high, less than 400 mm above the reactor core, in agreement with similar experiments reported by Rao et al. (1988) [11].

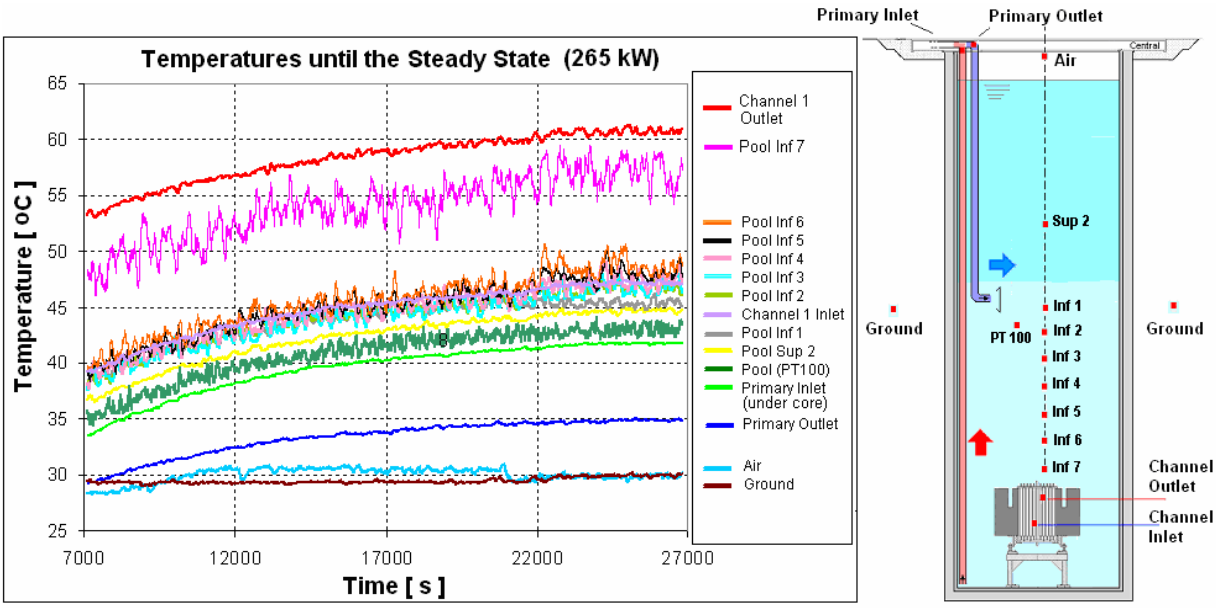

Figure 8. Temperatures patterns at 265 kW thermal power

In steady state operation at 265 kW the pool cooling system was turned off during about 15 min. Figure 9 shows the behavior of fuel, channel outlet and pool average temperatures. The pool temperature begins to arise and the fuel and channel temperatures remain almost at the same values.

One type K thermocouple was put in Position 40 of the rotary specimen rack for about 2 hours with the IPR-R1 operating at the power of 100 kW. Figure 9 shows the results from the temperature data in the fuel element, reactor pool, reactor room and specimen rack. At this power the higher temperature in the irradiation facility was 41.5 °C.

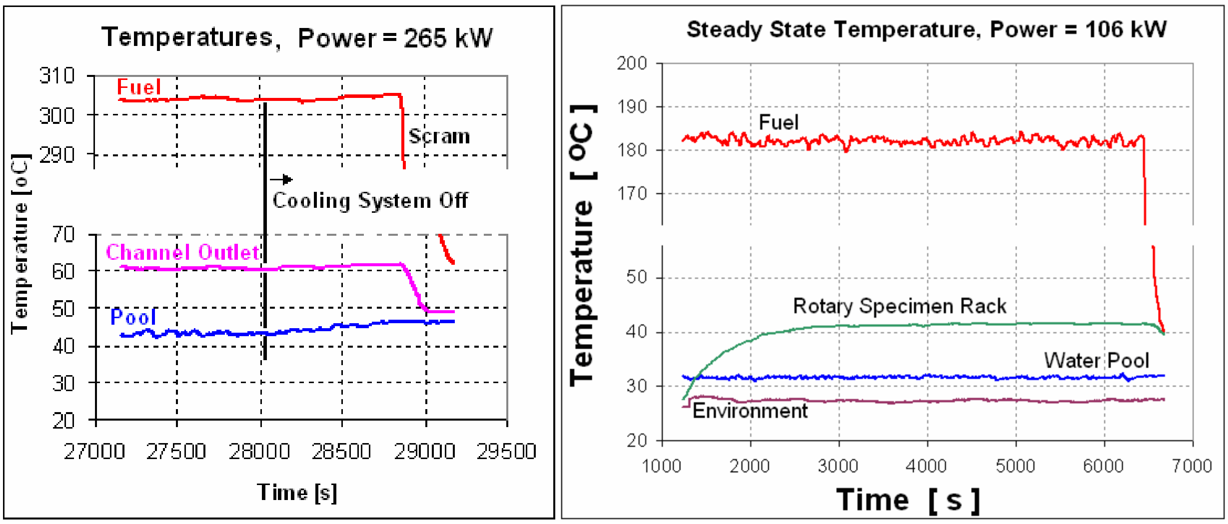

Figure 9. Temperature behavior after turning off the cooling system and the temperature evolution in Position 40 of the Rotary Specimen Rack

3. CONCLUSIONS

The experiments confirmed the efficiency of the free circulation in removing the heat produced in the reactor core by nuclear fission. The instrumented fuel temperature stayed almost constant at about 300 °C at 265 kW thermal power, with the primary cooling loop circulation turned off. The data taken during the experiments provides an excellent picture of the thermal performance of the IPR-R1 Reactor. The experimental data also provides information, which allows the computation of other parameters, such as the flow velocity through the core and the heat transfer coefficient [12]. The theoretical temperatures and flow velocity were determined under ideal conditions [7]. The actual coolant flow is quite different because of the inflow of water from the core sides (colder than its center). There is a considerable coolant crossflow throughout the channels. The temperature measurements above the IPR-R1 core showed that water mixing occurs within the first few centimeters above the top of the core, resulting in an almost uniform water temperature. Finally, the temperature at the primary loop suction point at the pool bottom has been found as the lowest temperature in the reactor pool.

4. ACKNOWLEDGMENTS

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